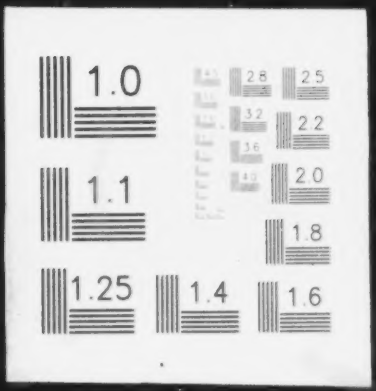
1.0
1.1
1.25
1.4
1.6
1.8
2.0
2.2
2.5
2.8
3.2
3.6
4.0

Geological Survey
of Canada

CURRENT RESEARCH
2002-E11

Refraction seismic studies in Nares Strait between Ellesmere Island, Nunavut, and northwest Greenland

Thomas Funck, H. Ruth Jackson, Ian D. Reid, and Sonya A. Dehler

2002

Natural Resources Canada
Ressources naturelles Canada

Canada

©Her Majesty the Queen in Right of Canada 2002
ISSN 1701-4387
Catalogue No. M44-2002/E11E
ISBN 0-660-18853-8

Available in Canada from the
Geological Survey of Canada Bookstore website at:
http://www.nrcan.gc.ca/gsc/bookstore (Toll-free: 1-888-252-4301)

A copy of this publication is also available for reference by depository libraries across Canada through access to the Depository Services Program's website at http://dsp-psd.pwgsc.gc.ca

Price subject to change without notice

All requests for permission to reproduce this work, in whole or in part, for purposes of commercial use, resale, or redistribution shall be addressed to: Earth Sciences Sector Information Division, Room 402, 601 Booth Street, Ottawa, Ontario K1A 0E8.

Authors' addresses

T. Funck (tf@dlc.ku.dk)
Danish Lithosphere Centre
Øster Voldgade 10 L
DK-1350 Copenhagen K, Denmark

H.R. Jackson (rujackson@nrcan.gc.ca)
S.A. Dehler (sdehler@nrcan.gc.ca)
1 Challenger Drive
(P.O. Box 1006)
GSC Atlantic
Dartmouth, Nova Scotia
B2Y 4A2

I.D. Reid (idr@geo.geol.ku.dk)
Geological Institute
University of Copenhagen
Øster Voldgade 10, DK-1350
Copenhagen K, Denmark

Publication approved by GSC Atlantic

103-04440/

Refraction seismic studies in Nares Strait between Ellesmere Island, Nunavut, and northwest Greenland

Thomas Funck, H. Ruth Jackson, Ian D. Reid, and Sonya A. Dehler

Funck, T., Jackson, H.R., Reid, I.D., and Dehler, S.A., 2002: Refraction seismic studies in Nares Strait between Ellesmere Island, Nunavut, and northwest Greenland; Geological Survey of Canada, Current Research 2002-E11, 6 p.

Abstract: A refraction/wide-angle reflection seismic experiment consisting of three lines in the Nares Strait region between Ellesmere Island and northwest Greenland was carried out from August 6 to September 8, 2001, as part of a multidisciplinary program. The overall objective of the program is to provide new information on the origin of Nares Strait and shed insight on the controversy over its development. To run the experiment in the ice-choked waters, Canada's largest icebreaker, the CCGS *Louis S. St. Laurent*, was required along with two ship-based helicopters.

The main refraction/wide-angle seismic line was located between Makinson Inlet on Ellesmere Island and Thule Air Base in Greenland. Initial analysis of the seismic data shows a clearly defined high-amplitude Moho reflection with a lateral correlation of >150 km. Crustal thickness on the eastern end of the line (Greenland) is estimated to be approximately 35 km using a simple one-dimensional velocity structure.

Résumé : Entre le 6 août et le 8 septembre 2001, on a réalisé une expérience de sismique réfraction et de sismique réflexion grand angle dans le cadre d'un programme multidisciplinaire. L'expérience comportait l'enregistrement de trois profils sismiques dans la région du détroit de Nares, entre l'île d'Ellesmere et le nord-ouest du Groenland. Le programme avait pour objet global d'obtenir de nouveaux renseignements sur l'origine du détroit de Nares et de faire la lumière sur sa formation. Afin de pouvoir effectuer les travaux dans les eaux glacées de cette région, on a fait appel au plus grand brise-glace canadien, le NGCC *Louis S. St-Laurent*, ainsi qu'à deux hélicoptères embarqués.

Le principal profil de sismique réfraction/sismique réflexion grand angle s'étendait entre l'inlet Makinson, dans l'île d'Ellesmere, et la base aérienne Thule, au Groenland. Une première analyse des données sismiques révèle la présence d'une réflexion du Moho de forte amplitude bien définie à corrélation latérale de plus de 150 km. En utilisant une structure de vitesse unidimensionnelle simple, on a pu estimer à environ 35 km l'épaisseur de la croûte à l'extrémité est (Groenland) du profil.

INTRODUCTION

The evolution of the Nares Strait region (Fig. 1) has been the subject of a long-standing controversy (Dawes and Kerr, 1982). Three hypotheses were developed for the geodynamic evolution of the area. 1) Nares Strait is a major strike-slip fault. 2) Plate motion has been taken up first by strike slip along the strait, followed by compression in a broad zone on Ellesmere Island (Eurekan fold belt), while Greenland was not much influenced by the Eurekan Orogeny. An updated version of this model is presented by Tessensohn and Piepjohn (2000). 3) Nares Strait is a nontectonic boundary and the geology can be correlated across it.

The controversy resulted from an apparent incompatibility between the onshore geology surrounding Nares Strait and plate tectonic models describing the opening of the North Atlantic and the resulting motions of Greenland. To test the three hypotheses it is essential to map the geology between Ellesmere Island and Greenland using geophysical methods. The multidisciplinary experiment in the summer of 2001 was designed to integrate targeted onshore geological field work with regional geophysical measurements so as to extend interpretations off shore.

THE MULTIDISCIPLINARY EXPERIMENT

The multidisciplinary study of the Nares Strait region (Jackson and Shipboard Scientific Party, 2002) was organized by the German Federal Institute for Geosciences and Natural Resources (BGR) and the Geological Survey of Canada (GSC). Scientists from other countries were invited to support the program.

Figure 1 shows the 6578 km long track of the CCGS *Louis S. St. Laurent* (Fig. 2). The BGR collected a total of 1200 km of reflection seismic data in southern and northern Nares Strait. Ice conditions (>90% cover) in Kane Basin prohibited data acquisition in the central part of the strait. The length of the streamer was adapted to the ice conditions and varied between 1200 m (48 channels) and 150 m (6 channels). Helicopters (type MBB BO-105) were used to acquire 9000 km of

Figure 1. *Topographic map (data source: International Bathymetric Chart of the Arctic Ocean; Jakobsson et al., 2000) of the Nares Strait region showing the ship track of the icebreaker CCGS* Louis S. St. Laurent *during the multidisciplinary experiment. The cruise started on August 6, 2001, in Resolute, Canada, and ended on September 8, 2001, in Thule, Greenland.*

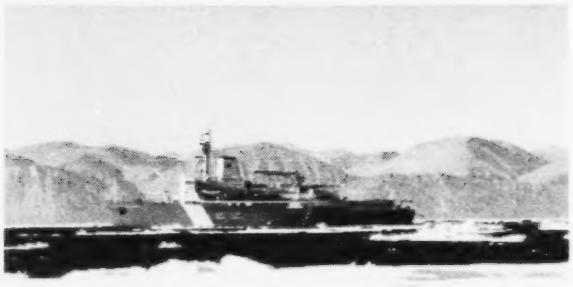

Figure 2. *Canadian Coast Guard Ship (CCGS)* Louis S. St. Laurent *in Kennedy Channel (northern Nares Strait) on August 20, 2001. The 120 m long icebreaker is towing the airgun array in preparation for shooting along refraction seismic lines 1 and 2. The background shows Ellesmere Island.*

aeromagnetic data in northern Nares Strait and southern Kane Basin. Onshore geological work included sampling for fission track and palaeomagnetic studies.

In addition, the ship and helicopters were used to perform geodetic (GPS measurements), climatological (sediment coring and high-resolution reflection seismic profiling), hydrographic (charting), oceanographic (CTD and water samples), and biological (marine mammal observation) tasks. This paper describes the refraction/wide-angle seismic component of the project, which involved scientists from the Danish Lithosphere Centre, the Geological Institute at the University of Copenhagen, and the GSC.

THE REFRACTION SEISMIC EXPERIMENT

Equipment and logistics

The CCGS *Louis S. St. Laurent* was used to deploy ocean-bottom seismometers owned by the GSC and by Dalhousie University, Halifax, Nova Scotia. A total of 10 ocean-bottom seismometers were equipped with three-component geophones (one vertical and two horizontal components) and a hydrophone. Seven ORION land seismometers (GSC; equipped with three-component geophones) were maintained in shipboard laboratories and deployed by helicopter.

Two seismic sources were available for the project. The primary source was the GSC airgun array consisting of six 1000 in.^{3} (16.4 L) guns. The guns were towed 30 m behind the ship at a depth of 6 m. The second source was an array of six Sodera GI airguns (2 at 255 in.^{3} (4.18 L), 2 at 210 in.^{3} (3.44 L), and 2 at 155 in.^{3} (2.54 L)) with a total volume of 20.3 L, which was used primarily for the reflection seismic profiling. This array was towed at a depth of 3 m. Shot positions and receiver locations were calculated from the ship's global positioning system (GPS) recordings.

Ice conditions in Nares Strait were worse than average and plans had to be modified several times. The original plan to shoot two long refraction seismic lines in Kane Basin and Kennedy Channel across a prominent gravity low had to be given up. Large ice-free areas were encountered only in southern Nares Strait.

Lines 1 and 2

Ice conditions in Kennedy Channel (Fig. 3) prevented the use of the full streamer length during the reflection seismic work and thereby reduced our ability to obtain good velocity information at deeper levels. Hence, refraction/wide-angle reflection seismic data were collected to determine the velocity structure within the sediments and the upper crust.

The high risks of using ocean-bottom seismometers in the ice-infested waters were avoided by deploying a landstation on Hans Island, a small island in the middle of Kennedy Channel. Two additional ORION landstations were flown to Carl Ritter Bay on Ellesmere Island and to Fossil Bay, Greenland.

Since imaging of the upper crust was of primary interest, the smaller GI-airgun array was used for shooting. The shot spacing was 15 seconds, which corresponds to a nominal shot spacing of about 30 m given the ship's speed of 4 knots.

The original plan for this line was to shoot from Carl Ritter Bay to Fossil Bay while passing as close as possible to Hans Island. However, ice conditions worsened and precluded the deployment of the airgun array close to Carl Ritter Bay. Instead, the ship sailed some 20 km south along the coast of

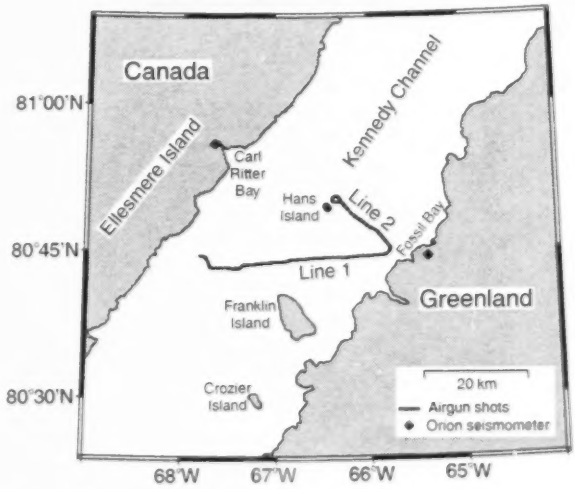

Figure 3. *Location map of refraction seismic lines 1 and 2 in Kennedy Channel. Solid lines show the shot locations and diamonds indicate landstation positions.*

Ellesmere Island where the ice cover finally allowed a deployment of the airguns. From here the ship sailed to Fossil Bay (line 1) and then turned toward Hans Island and Carl Ritter Bay (line 2). Once passed Hans Island, the ice cover again became so dense that the airguns had to be retrieved.

Line 3

Ice conditions in northernmost Baffin Bay allowed a refraction/wide-angle reflection seismic line with offsets large enough to record Moho reflections. Line 3 (Fig. 4) runs from Thule Air Base across southern Nares Strait and into Makinson Inlet on Ellesmere Island.

It was known from ice charts that conditions at the entrance to Makinson Inlet would be difficult (ice cover 40–90%). When the ship entered the area it was deemed too risky to deploy any ocean-bottom seismometers west of longitude 76°W, as moving ice could have prevented instrument recovery. Eight ocean-bottom seismometers (stations 8 through 15) were deployed in Baffin Bay. One ORION landstation was deployed at the end of Stenkul Fiord in western Ellesmere Island (station 1) and five other stations were deployed along Makinson Inlet and Smith Bay (stations 2 through 6). On the Greenland side, one ORION station was deployed on Saunders Island (station 16). Additional recordings were obtained from a temporary broadband seismometer at Thule Air Base (station 17), which was deployed as part of the GLATIS project (T. Dahl-Jensen, pers. comm., 2001).

The shooting started off Saunders Island using the 6000 in.^{3} (98.4 L) airgun array. A shot interval of 60 seconds resulted in an average shot spacing of 128 m. Bad weather hampered the shooting and conditions worsened as the ship passed Steensby Land, which had previously offered some protection from the northerly winds. Later, the wind speed increased to 50 knots with gusts up to 100 knots. West of ocean-bottom seismometer 8, the ship encountered ice floes and the airguns were retrieved when ice the size of cars began hitting the array. The ship then proceeded to the end of

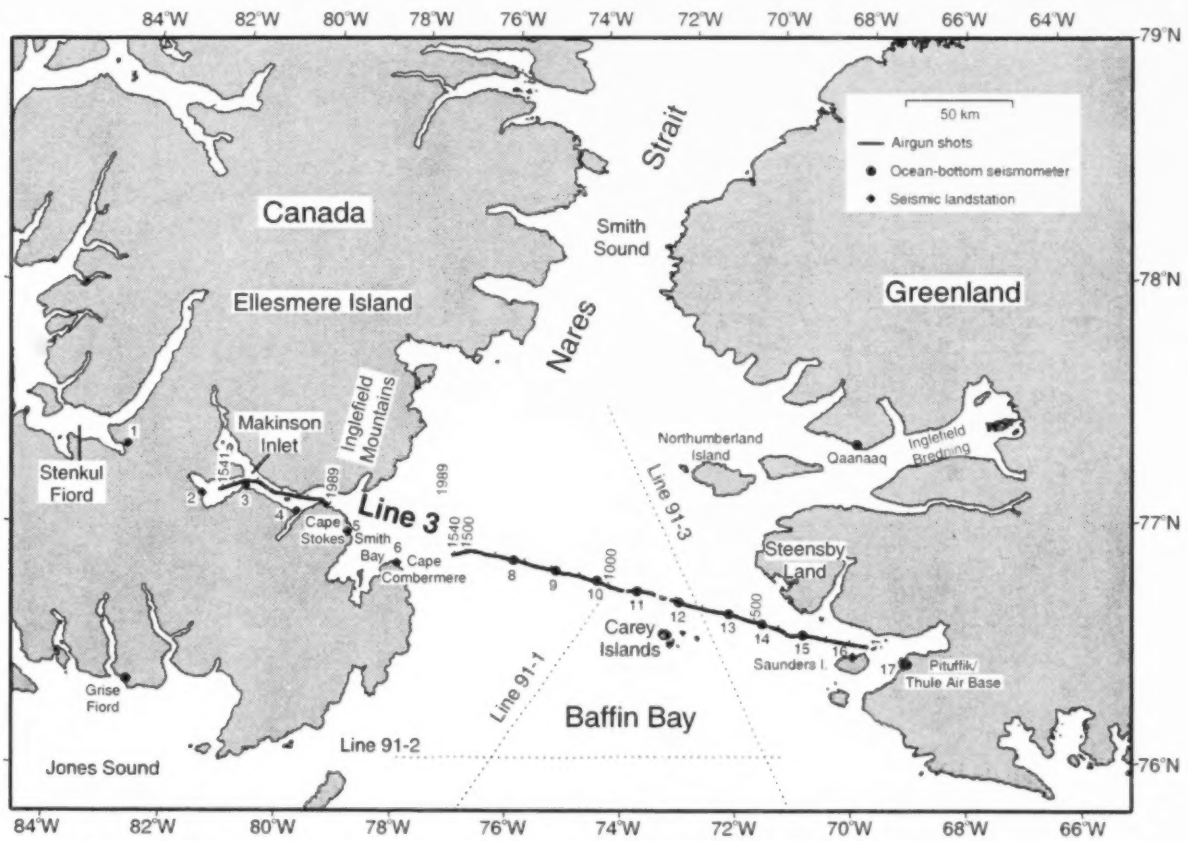

Figure 4. *Location map of refraction seismic line 3 (solid line) in northern Baffin Bay. Numbers along the line indicate the shot number (tick interval is 100 shots). Ocean-bottom seismometer locations are indicated by circles and landstations are marked by diamonds. Location of the refraction/wide-angle reflection seismic lines from the 1991 experiment are shown as dashed lines (Jackson and Reid, 1994; Reid and Jackson, 1997).*

Makinson Inlet where the airguns were deployed in the nearly ice-free fiord. Shooting was resumed seaward until dense ice at western Nares Strait was again encountered. The total shot gap due to the ice was 63 km.

During instrument recovery, a polar bear was observed close to landstation 5 at Cape Stokes and it turned out that the station had been disturbed by the bear. The damage was limited to a few pulled cables and some early data could be retrieved.

RESULTS

Initial processing of the data along line 3 shows that seismic energy was recorded for offsets of up to 220 km. The gale-force winds reduced the signal-to-noise ratio slightly, but less than expected or feared. Coherency mixing and other processing techniques should help to improve the record.

Figure 5 shows the vertical component of the Thule broadband seismometer (station 17), in which all major seismic phases are recognized. An upper crustal refraction (P_g) with a phase velocity of 6.5 km/s can be seen up to an offset of 42 km where the amplitude starts to fade. The corresponding shear wave phase S_g has a phase velocity of 3.6 km/s. The mid-crustal boundary is imaged by the P_cP reflection. This phase has a high amplitude west of 62 km, but can also be seen farther eastwards as a weak arrival. The most prominent phase is the Moho reflection P_mP, which can be correlated from offsets as close as 40 km and up to 192 km. Some weak energy can be seen around 200 km, which probably represents the upper mantle refraction P_n.

The well defined P_mP phase indicates a sharp crust–mantle boundary. This interpretation could explain the recording of a high-amplitude phase between 70 and 90 km some 5.5 s behind the P_mP phase, which is tentatively interpreted as P_mS phase (P to S conversion at the Moho). According to Guest et al. (1993), a sharp Moho transition is required to generate strong P_mS reflections.

Simple one-dimensional traveltime modelling of the P_mP phase of station 17 indicates a Moho depth of approximately 35 km at the eastern end of the line. This model uses the velocity-depth profile of Line 91-3 (Fig. 4) of Jackson and Reid (1994). Full two-dimensional velocity modelling of the entire data set will show the lateral variations in crustal thickness and velocity toward Ellesmere Island. Results from an earlier refraction/wide-angle reflection seismic study (Reid and Jackson, 1997) farther to the south (Line 91-2; Fig. 4) show a thinning of the crust with a Moho depth of 16 km beneath the Carey Basin, compared to 21 km at the western and eastern end of the line. Reid and Jackson (1997) interpret the narrow and linear basin as the possible delineation of a former plate boundary.

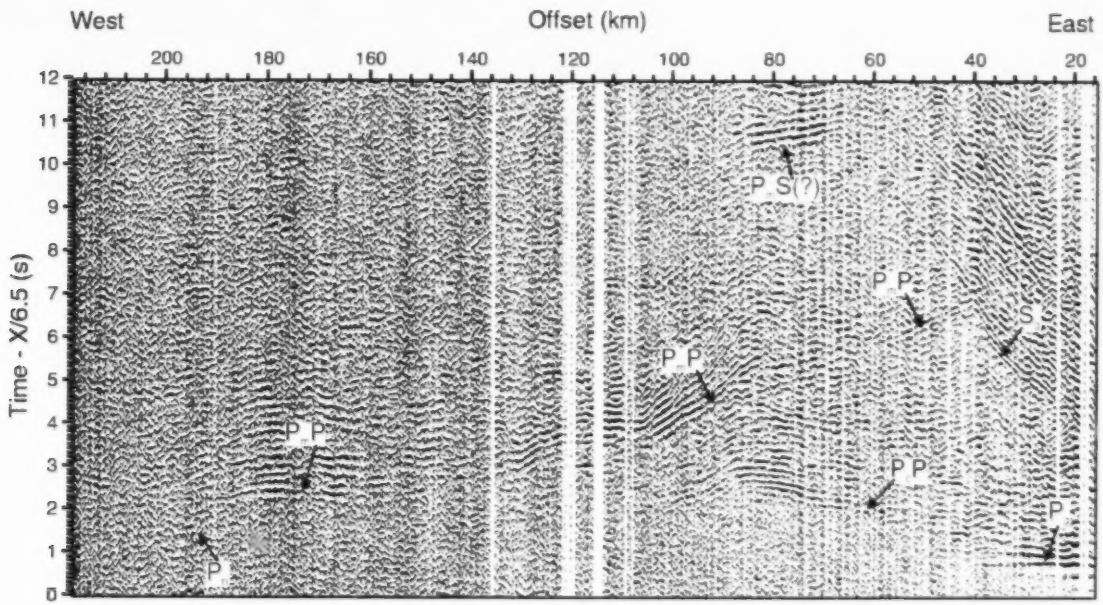

Figure 5. *Record section of the vertical component of station 17 (broadband seismometer at Thule Air Base) showing shots 1 to 1540 of line 3 in Baffin Bay. Major phases are indicated by arrows. The horizontal scale is shot-receiver distance and the vertical scale is traveltime displayed with a reduction velocity of 6.5 km/s. Processing includes a 4 to 10 Hz bandpass-filter, deconvolution, and trace scaling by range.*

ACKNOWLEDGMENTS

The Nares Strait cruise was funded by the BGR and the GSC. Data processing and analysis at the Danish Lithosphere Centre are covered by grants of the Danish National Research Foundation. We are grateful to captain Stewart Klebert, the crew, and the scientific staff of CCGS *Louis S. St. Laurent* for their support during the cruise. We thank helicopter pilots Adrien Godin and Harrison Macrae for their help in deploying the landstations. Technical support for ocean-bottom seismometer and airgun operations by Borden Chapman, Larry Johnston, and Cory Nixon is greatly acknowledged. Trine Dahl-Jensen provided the data from the broadband seismometer in Thule

REFERENCES

Dawes, P.R. and Kerr, J.W.
1982: Nares Strait and the drift of Greenland: a conflict in plate tectonic: Meddelelser om Gronland, v. 8, 392 p.

Guest, W.S., Thomson, C.J., and Spencer, C.P.
1993: Anisotropic reflection and transmission calculations with application to a crustal seismic survey from the East Greenland shelf: Journal of Geophysical Research, v. 98, p. 14 161–14 184.

Jackson, H.R. and Reid, I.
1994: Crustal thickness variations between the Greenland and Ellesmere Island margins determined from seismic refraction: Canadian Journal of Earth Sciences, v. 31, p. 1407–1418.

Jackson, H.R. and Shipboard Scientific Party
2002: Cruise 2001 Louis S. St. Laurent PASSAGE Pathway to the Arctic Seismic Survey and Geoscientific Experiment, Resolute, Nunavut, to Thule, Greenland: Geological Survey of Canada, Open File 4282, 152 p.

Jakobsson, M., Cherkis, N.Z., Woodward, J., Macnab, R., and Coakley, B.
2000: New grid of Arctic bathymetry aids scientists and mapmakers: EOS Transactions, American Geophysical Union, v. 81, p. 89–96.

Reid, I. and Jackson, H.R.
1997: Crustal structure of northern Baffin Bay: seismic refraction results and tectonic implications: Journal of Geophysical Research, v. 102, p. 523–542.

Tessensohn, F. and Piepjohn, K.
2000: Eocene compressive deformation in Arctic Canada, North Greenland and Svalbard and its plate tectonic causes: Polarforschung, v. 68, p. 121–124.

Geological Survey of Canada Project PS2002